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# An Optimization Model in Commodity Mode Choice Transportation System

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## ABSTRACT

the research method and algorithm used in this study were able to achieve significant results. The proposed model is not only theoretically strong and reliable, but also in practice it has been able to show better performance than other similar models. In general, the use of the cuckoo search algorithm has played a key role in this research due to its unique capabilities in searching for global optimal and interacting with complex data. The results obtained from the case study showed that the proposed model can be effectively used in optimizing supply chains and combined transportation in transit corridors such as the North-South Corridor. The proposed model, using the cuckoo search algorithm, was able to achieve significant results in reducing transportation costs and times. These results indicate the efficiency of the model in optimizing routes and selecting the best transportation methods according to existing conditions and constraints. The results showed that this model was able to achieve the best route and method of transportation in this corridor by significantly reducing transportation costs and times (10-20) percent. Therefore, it includes 1916 kilometers in length and 57 hours of time, and it costs about 38 cents per kilometer of travel. In this optimal route, 57% of the rail transportation route and 43% of the road transportation were used, and also a sensitivity analysis was performed to changes in transportation speed, interest rate, and other key parameters, which confirmed the stability and flexibility of the model.

**Keywords:** Transportation Systems, Optimization Modelling, optimal route, Cuckoo Search Method

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## 1. INTRODUCTION

Transportation in the supply chain refers to the movement of products from one location to another, starting at the beginning of the supply chain when materials enter the warehouse and continuing with a customer order that is delivered on

site to the end user [1]. The cost of transporting goods in the United States is about 6% of GDP, meaning that a large portion of a company's supply chain costs comes from transportation [2]. Many manufacturers and retailers have found that they can use state-of-

the-art supply chain management to reduce inventory and warehousing costs while accelerating delivery to the end customer. The success of any supply chain is closely linked to the proper use of transportation. When transportation costs are high, even seemingly small oversights can lead to unnecessary costs that could be avoided, thereby reducing overall profit margins [3].

Combined or multimodal transportation is recognized as one of the most important transportation methods in the supply chain. In this method, goods are transported from origin to destination using several different means of transportation (such as trucks, trains, and ships). This method is considered an optimal and efficient approach to moving goods due to the combination of the various advantages of each vehicle, including cost reduction, speed increase, and productivity improvement [4]. The importance of this research is that by optimizing combined transportation processes, logistics costs can be reduced, customer satisfaction can be increased, and overall supply chain performance can be improved.

Cost and time optimization in combined transportation is a major challenge in the supply chain [5]. Given the complexities and various interactions between transportation vehicles, there is a need for advanced analytical and optimization tools. In this regard, metaheuristic algorithms are proposed as one of the efficient methods for solving complex optimization problems [6]. These algorithms, including the cuckoo search algorithm, have the ability to find optimal solutions to complex and multifaceted problems. Using these algorithms in combined transportation optimization can help reduce transportation costs and time, increase efficiency and flexibility of the supply chain [7,8].

The basic idea of intermodal transport is to consolidate loads for efficient long-distance transport (e.g. by rail or large ocean-going vessels), while benefiting from the efficiency of local trucking operations. This explains the importance of container-based transport. Intermodal transport of cargo often equates to moving containers over long distances through intermodal chains [9].

In the 2019 study titled Optimization Model in Logistics and Supply Chain Planning, Silain et al.

considered the progress and success of a company to be a key success factor, from the perspective of consumer response to production in all aspects of each company's activity. In this case, the supply chain optimization problem is explained from the perspective of logistics provision, including a mathematical model of cost optimization for supply chains in the form of MILP (mixed integer linear). Production, transportation and distribution costs are chosen as optimization criteria. Time, volume, capacity and mode of transportation are also considered. This model is developed based on the theory of supply chain management to achieve the lowest cost, responsiveness and achievement of common goals [10].

According to the paper by Atmayudha et al. in 2021, crude oil logistics activities, which are mostly carried out using ships, are one of the factors of greenhouse gas emissions. It is predicted that greenhouse gas emissions from logistics activities will increase significantly by 2050, so they need to be controlled with an appropriate logistics planning strategy. The aim of this study is to apply the concept of green logistics to crude oil transportation, which considers multiple warehouses and heterogeneous fleets using multi-objective optimization [11].

In a paper titled An Integrated AHP-DEA Multi-Objective Optimization Model for Sustainable Transportation in the Mining Industry, Gupta et al. (2021) formulated an integrated multi-objective optimization model for a sustainable transportation problem with expanded capacity in the coal mining industry using analytic hierarchy process (AHP) and data envelopment analysis (DEA) techniques [12,13]. Compared with existing research on the multi-objective transportation problem, the proposed integrated model provides trade-off solutions using the real-world objectives of minimizing transportation cost, maximizing efficiency scores and priority weights of vehicle types, and minimizing greenhouse gas emissions from selected vehicles [14]. To the best of the author's knowledge, these objectives have not been comprehensively analyzed together before [15-18]. In the above study, the AHP technique was used to determine the priority weights of vehicle types that are maximized in the integrated multi-objective optimization model. Such an approach can select vehicles that rank high in the

AHP hierarchy and also satisfy other requirements of the transportation problem to the best extent possible. Some of the main features, including sustainable transportation systems, transportation modes, and alternative fuel vehicle characteristics, were investigated from a sustainability perspective, especially in the context of coal mining industries. Multi-objective transportation route optimization for hazardous materials based on geographic information system is the title of the paper in 2020. Safety and security are of great importance, and it is important to optimize and improve the routes of trucks carrying hazardous materials. In this study, we complete the case analysis of the proposed method to determine highway sections in Jiangsu Province, China, and test the above algorithm on the network, which has 144 nodes and 388 sections. The results we obtain show that the building factors play a very important role in the model, and the multi-objective mixed integer linear optimization model is reasonable and has good quality [19].

In this paper, Manif and Bouamama (2017) propose a multi-objective fireworks algorithm based on the Pareto dominance method to select an optimistic solution to the multimodal transportation problem. The objective is to determine the shortest and most efficient travel plan to satisfy a given set of operational demands and constraints. Several publications have been published in recent years documenting the analysis of transportation networks. This fact indicates the importance and complexity of this problem. In order to achieve a sustainable planning in a relatively complex transportation system, it is of great interest to use an approach that

belongs to the field of artificial intelligence methods [20].

Roookhosh et al. (2024) present a dual-objective optimization model for a sustainable supply chain, using incremental manufacturing to reduce waste and costs. His research method combines traditional and additive manufacturing methods to create an optimization model that uses optimization techniques to reduce waste and costs in the supply chain [21].

Shoukat and Xiaoqiang also investigate the green and economical supply chain in intermodal distribution using novel evolutionary algorithms. Research Methodology This research uses an innovative evolutionary algorithm to optimize intermodal distribution and reduce supply chain costs. This research specifically focuses on the distribution of covered boards in the supply chain [22].

Li and Mo analyze and optimize the intermodal air-rail transportation network using a stochastic Petri net model. In this research, a stochastic Petri net model is used to model and optimize intermodal transportation routes. This model analyzes and optimizes transportation flows in air and rail networks [23]. Zhang et al. also studied the optimization of emergency evacuation planning in a multimodal urban transportation network. A dynamic optimization model is presented for emergency evacuation planning in multimodal transportation networks. This model analyzes and optimizes evacuation routes in emergency situations [24].

## 2. METHODOLOGY

In this research, the main goal of finding the shortest and fastest route is to reduce the cost by reducing the distance traveled and increasing the speed (reducing time) for transporting goods. Since exact algorithms, although capable of finding the optimal solution, do not have the necessary efficiency when the problem under consideration is an NP-hard problem, and their solution time will increase exponentially, we use

metaheuristic algorithms with innovation to solve the problem under consideration. For this purpose, one of the algorithms that can have high performance in finding the optimal solution is the cuckoo search algorithm. This algorithm, using the Levi flight strategy, allows for deeper search and avoidance of local optima.

## 2.1. Objective function and parameters

The final objective function is as follows:

$$\begin{aligned} \text{Minimize } Z = & \sum_{(i,j,k)} C_{ij}^k x_{ij}^k + \sum_{(i,j,k,l)} L_j^{kl} y_i^{kl} \\ & + \sum_{(i,j,k)} T_{ij}^k x_{ij}^k + \sum_{(i,j,k,l)} S_j^{kl} y_i^{kl} \\ & + \sum_{(i,j,k,l)} M(u_i^{kl} - 1) \end{aligned} \quad (1)$$

The final objective function statements are as follows:

1- Freight costs  $\sum_{(i,j,k)} C_{ij}^k x_{ij}^k$

$C_{ij}^k$  : The cost of transporting cargo from point i to j using transportation method k.

$x_{ij}^k$  : Decision variable indicating whether the load is transferred from i to j using transportation method k (usually a binary variable of 0 or 1).

This part of the objective function is related to minimizing direct transportation costs.

2-Direct cost of changing the method of transportation, unloading and loading  $\sum_{(i,j,k,l)} L_j^{kl} y_i^{kl}$

$L_j^{kl}$  : The cost of changing the mode of transport from k to l and the costs associated with loading and unloading at point j.

$y_i^{kl}$  Decision variable indicating whether the change in transportation method from k to l will be made at point i.

This part of the objective function: considers the costs associated with changing the method of transportation and loading.

3- Time value of money cost of transportation

$\sum_{(i,j,k)} T_{ij}^k x_{ij}^k$

$T_{ij}^k$  : Time cost of transporting cargo from point i to j using transportation method k.

$x_{ij}^k$  : The same decision variable for transporting cargo from i to j by method k.

This part of the objective function: takes into account the time costs associated with transportation, which may include transfer time, waiting time, etc.

4- The cost of wasting time due to changing the method of transportation, unloading and loading .

$\sum_{(i,j,k,l)} S_j^{kl} y_i^{kl}$

$S_j^{kl}$  : The time loss cost associated with changing transportation method from k to l at point j.

$y_i^{kl}$  : Decision variable indicating whether the change in transportation method from k to l is made at point i.

This part of the objective function: takes into account the additional time costs associated with changing the transportation method and reloading.

5- Large numbers and fines  $\sum_{(i,j,k,l)} M(u_i^{kl} - 1)$

$M$  : A large number intended for the purpose of fines.

$u_i^{kl}$  : A variable that represents a specific condition in the problem, such as not changing the transportation method or not using illegal and incorrect combinations in changing the transportation method, can be compensated for and erroneous data can be removed with this variable.

This part of the objective function: is intended to penalize solutions that violate certain conditions or impose unnecessary additional costs.

## 2.2. Problem constraints

For the above objective function, constraints can be recommended that help optimize the problem and ensure that the model correctly considers operational constraints and real-world conditions. Several important constraints are mentioned below:

1-Goods flow constraint

Objective: Ensure that the amount of cargo entering a point is equal to the amount of cargo leaving that point (except for the origin and destination points).

$$\sum_j x_{ij}^k = \sum_l x_{ji}^k \quad \forall i, k \quad (2)$$

This constraint states that the inflow and outflow to/from each point i must be equal.

2- Integrity constraint

Objective: Ensure that decision variables  $x_{ij}^k$  and  $y_{ij}^k$  are binary (0 or 1).

$$x_{ij}^k, y_{ij}^k \in [0,1] \quad (3)$$

This constraint says that the load either uses transportation method k or does not (1 or 0), and the change of transportation method either occurs or does not occur.

### 3- Capacity constraint constraint

Objective: Ensure that the transportation capacity by method k on route i to j does not exceed the allowed limit .

$$Capacity_k \geq \sum_j x_{ij}^k \quad \forall i, j, k \quad (4)$$

This constraint states that the total amount of cargo transported on route i to j must not exceed the capacity of transportation method k.

### 4- Time constraint

Objective: Ensure that the total transportation time on each route is less than a certain limit.

$$Time\ Limit \geq Time(\sum_{(i,j,k)} T_{ij}^k x_{ij}^k + \sum_{(i,j,k,l)} S_j^{kl} y_i^{kl}) \quad (5)$$

This constraint states that the total transportation time, including transfer and mode change times, must be within the allowable range.

### 5-Mode Change Constraint

Purpose: To limit the number of times a mode of transportation can be changed from one mode to another.

$$Max\ Switches \geq \sum_{(i)} y_i^{kl} \quad (6)$$

## 2.3. Case Study

The studied area is the Astara to Bandar Abbas route, which forms an important part of the North-South Corridor. Due to its strategic location and proximity to the northern borders of Iran and its proximity to the Caspian Sea, it is of great importance in regional trade exchanges. This route, due to the possibility of

This constraint states that the number of changes in the shipping method should not exceed a certain limit.

### 6- Allocation Constraint

Goal: To ensure that each shipment selects only one shipping method.

$$\sum_k x_{ij}^k = 1 \quad \forall i, j \quad (7)$$

This constraint states that for each pair of i and j, only one transportation method is chosen.

### 7-Penalty Constraint

Objective: To control and adjust penalties for specific conditions.

$$u_i^{kl} = 1 \text{ if condition is met, otherwise } 0 \quad (8)$$

This constraint adjusts the penalties based on specific conditions.

Considering all the above, the above model can be considered a multi-objective optimization model in combined and multimodal transportation in the supply chain of goods and evaluates and analyzes routing issues from two perspectives: cost and time.

using combined transportation (rail and road) and proximity to key ports such as Bandar Abbas, has unique capabilities to facilitate and accelerate the transportation of international transit goods and connect the inland transportation network to the international network.

## 2.4. Data Used

Distance between cities: Data on the distance between key points such as Astara, Bandar Abbas, and other important points along the North-South Corridor route has been collected. These distances have been used as the main inputs for calculating transportation costs and times.

Transportation methods: Data on the two main transportation methods, namely rail and road, have been used in this study. For each of these methods, the average speed and transportation cost per kilometer have been determined.

Transportation costs: The costs associated with each kilometer of transportation for rail and road methods have been calculated based on available information and standard rates. Although there were significant differences between the figures announced by transportation companies, international and domestic articles, reports and statistics announced, and other sources and references, in the end, a reasonable result was obtained. Based on [Table 1](#), the cost of each kilometer of rail and road transportation can be estimated in a specific manner, based on data collected from various sources.

**Table 1.** Rail and road transportation costs based on various sources

| Country Name        | Rail Freight    | Road Freight     |
|---------------------|-----------------|------------------|
| America             | \$0.70 - \$1.20 | \$1.00 - \$2.00  |
| Russia              | \$0.40 - \$0.66 | \$0.80 - \$1.20  |
| Australia           | \$0.60 - \$1.00 | \$1.20 - \$1.70  |
| Malaysia            | \$0.45 - \$0.68 | \$0.90 - \$1.360 |
| Singapore           | \$0.75 - \$1.10 | \$1.30 - \$1.80  |
| Germany/Netherlands | \$0.65 - \$1.10 | \$1.30- \$1.70   |
| Europe              | \$0.65 - \$1.10 | \$1.30- \$1.70   |
| China               | \$0.25 - \$0.65 | \$0.60 - \$1.30  |
| Saudi Arabia        | \$0.80 - \$1.35 | \$1.50 - \$2.50  |
| Japan               | \$0.65 - \$1.10 | \$1.30 - \$1.80  |
| India               | \$0.30 - \$0.45 | \$0.60 - \$0.85  |
| Turkey              | \$0.35- \$0.55  | \$0.60 - \$0.85  |
| Pakistan            | \$0.5 - \$0.66  | \$1.00 - \$1.32  |
| Iran                | \$0.20 - \$0.35 | \$0.30 - \$0.50  |

Transportation speed: The average transportation speed for rail and road methods is considered to be 35 km/h and 70 km/h, respectively. These speeds are used as the basis for calculating transportation time on different routes.

Cost of changing transportation method: To calculate the cost and time of changing transportation method, in case of changing from rail to road transportation, loading and unloading cost equal to \$60 and 5 hours

of additional time are considered. Conversely, in case of changing from road to rail, loading and unloading cost equal to \$30 and 3 hours of additional time are considered.

In the time value calculations, to convert transportation time into cost, the container occupancy cost, cargo value and bank interest are required, which are considered to be \$10 per day, \$42,000 and 12% per year, respectively.

**Table 2.** all distances of routes and modes of transportation in the network

| Origin | destination | Mode of transport | Distance   | Origin | destination | Mode of transport | Distance   |
|--------|-------------|-------------------|------------|--------|-------------|-------------------|------------|
| 1      | 2           | Road              | kilometers | 11     | 12          | Rail              | kilometers |
| 1      | 2           | Rail              | 79         | 12     | 14          | Road              | 152        |
| 1      | 3           | Road              | 95         | 12     | 15          | Road              | 110        |
| 1      | 3           | Rail              | 75         | 12     | 15          | Rail              | 174        |
| 2      | 4           | Road              | 164        | 12     | 18          | Rail              | 280        |
| 2      | 5           | Rail              | 157        | 12     | 12          | Road              | 540        |
| 2      | 6           | Road              | 175        | 13     | 15          | Road              | 135        |
| 3      | 7           | Rail              | 89         | 13     | 15          | Road              | 281        |
| 4      | 8           | Road              | 171        | 14     | 18          | Road              | 208        |
| 5      | 8           | Rail              | 251        | 14     | 16          | Road              | 383        |
| 6      | 3           | Road              | 172        | 15     | 17          | Road              | 316        |



|        |    |      |     |    |    |      |     |
|--------|----|------|-----|----|----|------|-----|
| 7      | 11 | Rail | 239 | 15 | 18 | Rail | 404 |
| 7      | 11 | Road | 152 | 15 | 18 | Road | 310 |
| 7      | 10 | Rail | 165 | 15 | 17 | Road | 300 |
| 7      | 12 | Road | 155 | 16 | 21 | Road | 173 |
| 8      | 7  | Rail | 260 | 17 | 19 | Rail | 576 |
| 8      | 7  | Road | 183 | 18 | 20 | Road | 367 |
| 9      | 9  | Rail | 171 | 18 | 20 | Road | 348 |
| 9      | 10 | Road | 307 | 18 | 21 | Road | 330 |
| 10     | 13 | Rail | 197 | 18 | 20 | Rail | 770 |
| 11     | 12 | Road | 189 | 19 | 21 | Road | 440 |
| Origin | 12 | Rail | 76  | 19 | 21 | Road | 311 |

## 4. RESULTS AND DISCUSSION

### 4.1. Results obtained from the proposed model

Based on the results extracted from the model, the most optimal route for combined transportation in the North-South Corridor transit route, focusing on the road and rail connection of Astara to Bandar Abbas, is route 1-3-7-10-12-15-18-21 or in other words Astara - Rasht - Qazvin - Saveh - Qom - Isfahan - Yazd - Bandar Abbas, which the total mileage based on calculations is 1916 km and the total time is calculated to be 57 hours. It should be noted that the route from Astara to Rasht is calculated

by rail, from Rasht to Qazvin and then Saveh and Qom by road, and from Qom to Isfahan, Yazd and Bandar Abbas again by rail. In [Figure 1](#), the text output of the above-mentioned items can be seen. The total cost of transportation and changing transportation methods and modes, based on model calculations, was found to be \$723.7, a figure of about 38 cents per kilometer, which is reasonable and reasonable .

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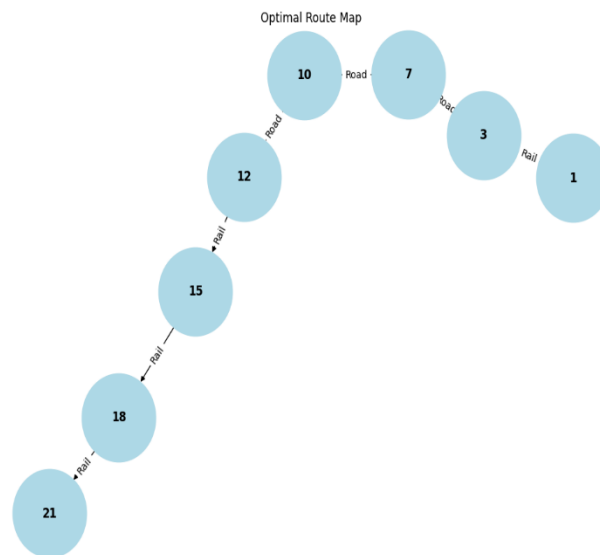
Best Route: [1, 3, 7, 10, 12, 15, 18, 21]
Total Cost: $723.6945205479452
Total Time: 57.0 hours
Total Distance: 1916 km
Transport Modes Used:
From 1 to 3: Rail
From 3 to 7: Road
From 7 to 10: Road
From 10 to 12: Road
From 12 to 15: Rail
From 15 to 18: Rail
From 18 to 21: Rail

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**Figure 1.** Model output for the most optimal model

[Figure 2](#) shows the optimal route map. This figure shows the best cost and time-optimized route selected by the proposed model. In this diagram, the optimal route from the starting point (node 1) to the ending point (node 21) is shown using rail and road

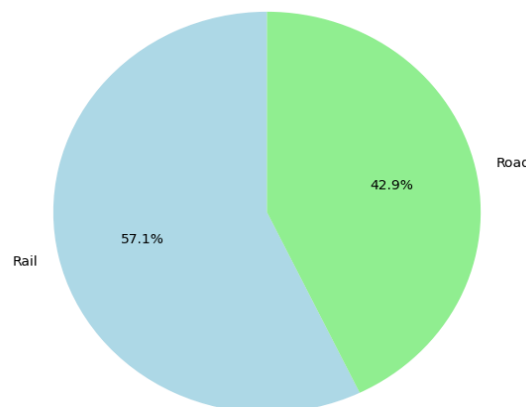
transportation methods. This route shows which parts of the route are best traveled by rail and which parts by road. The importance of this map is in showing the model's choices in the face of cost and time variations along different routes.



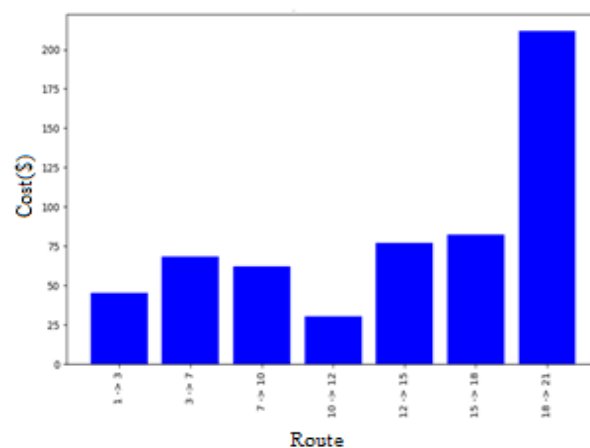
**Figure 2.** optimal route map and transportation method between both nodes

[Figure 3](#) shows the usage of transportation methods and the usage rate of each transportation method in the optimal route. This diagram shows how the usage of different transportation methods is divided in the optimization model. Here, we see what percentage of transportation is carried out by rail routes and what percentage by roads. According to the simulated data

and the algorithm used, it seems that the usage of rail transport (57.1%) is slightly superior to road transport (42.9%). This could indicate the greater efficiency of rail transport in the defined conditions, especially on longer routes where rail costs are more affordable.



**Figure 3.** Diagram of the use of transportation methods in the optimal route



**Figure 4.** Transportation cost chart per route



Figure 4 shows the transportation cost per route graph. This graph shows the transportation costs along different routes along the optimal route. Each bar in this graph represents the transportation cost between two specific nodes (cities). This graph clearly shows which parts of the route cost more than others and can help identify the points that need the most optimization.

Figure 5 shows the transportation time graph per route. This graph shows the transportation times along different routes along the optimal route. Similar to the cost graph, this graph also depicts the time spent on each route segment and shows which parts of the route require more transportation time. This information can help make better decisions to reduce unnecessary times.

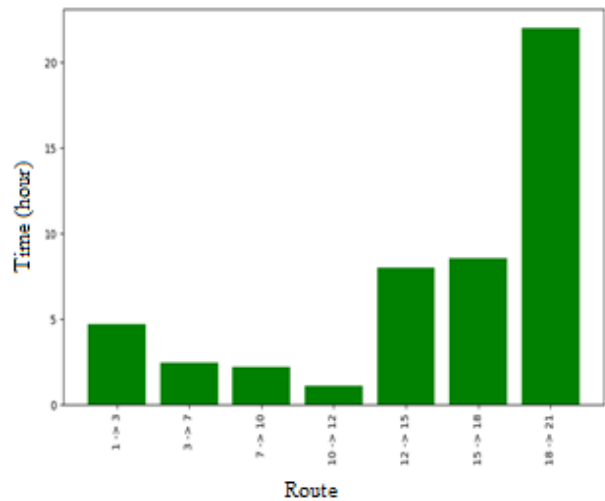


Figure 5. Transportation time chart for each route

Figure 6 shows the impact of changing the mode of transport on cost. This graph shows the impact of changing the mode of transport from rail to road and vice versa on total transport costs. The results of this graph indicate that changing the mode of transport

from rail to road has a greater impact on increasing costs than changing the mode from road to rail. This could be due to the higher costs and longer time associated with changing from rail to road.

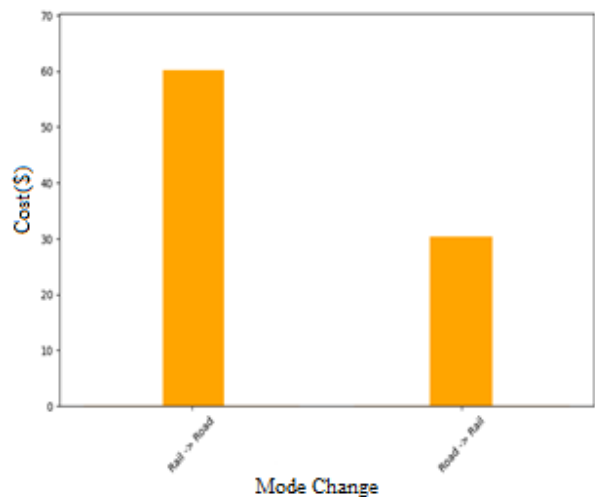
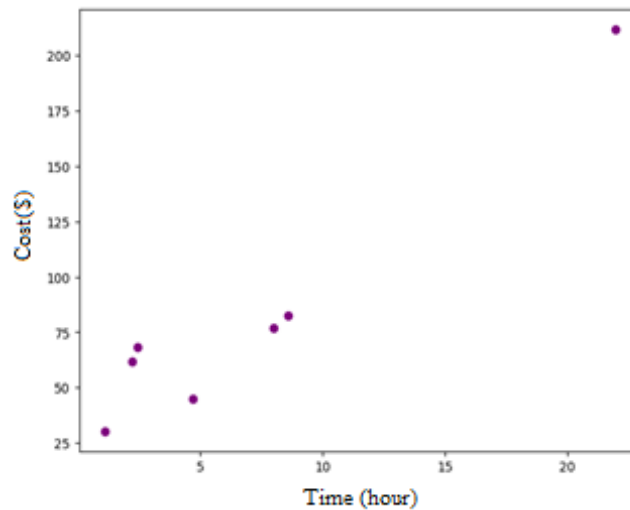


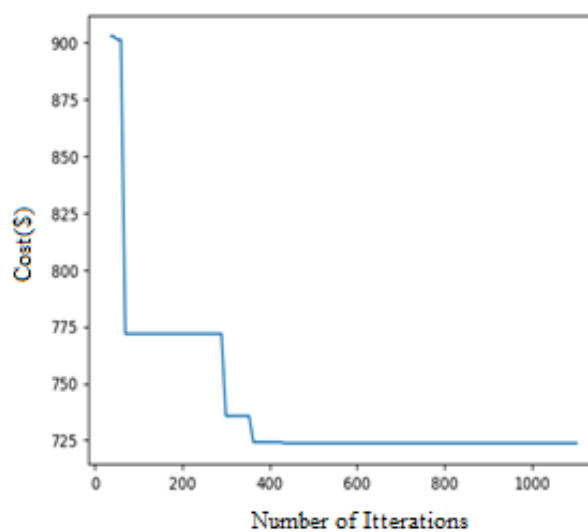
Figure 6. Cost diagram of changing transportation mode

Figure 7 is a cost versus time graph. This graph shows how changes in transit time can affect total cost. Here, we see that as transit time increases, costs also increase, although this increase may not be linear. This graph helps us understand how different

choices in transit speed and changing methods can help us make strategic decisions about reducing costs. With a larger number of points and route segments and more complex networks, this graph can provide important insights.



**Figure 7.** Cost - Time Graph



**Figure 8.** Model convergence diagram

[Figure 8](#) is a convergence diagram, which is one of the most important diagrams in modeling and optimization problems in the field of model efficiency. This diagram shows the convergence process of the optimization algorithm. As you can see, with the increase in the number of iterations, the final cost gradually decreases and reaches a constant value. This indicates that the cuckoo search algorithm has converged towards the best possible solution over time. This diagram shows the effectiveness of the algorithm in optimizing the transportation cost.

The convergence diagram shows the trend of the total transportation cost reduction during the execution of the cuckoo search algorithm. As can be seen in the diagram, in the early stages of execution, a significant reduction in costs occurs, indicating the ability of the algorithm to identify and eliminate suboptimal solutions in the initial iterations. This rapid reduction in costs in the early stages is due to

the large gap between the initial random costs and the more optimal costs to which the algorithm quickly moves.

As the algorithm progresses and the number of iterations increases, the rate of cost reduction gradually slows down and the convergence graph approaches a constant value. This phenomenon indicates that the algorithm is gradually converging towards an optimal point and has identified more optimal solutions. At this stage, the algorithm makes smaller improvements in costs instead of large changes, indicating that the algorithm is trying to find the best possible solution.

The remarkable thing about this graph is that after about 400 iterations, the cost approaches a constant value and the cost changes become very small. This indicates successful convergence of the algorithm and the achievement of an optimal limit in the solution space. The absence of large changes after this stage means that the algorithm has explored most

of the optimal solutions and has reached a point where further changes in subsequent iterations will not have a significant impact on the final cost.

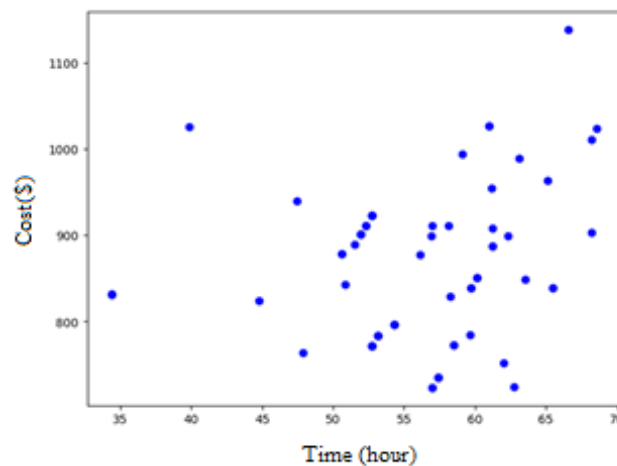
In some parts of the graph, it can also be seen that the algorithm has experienced temporary stability in some iterations, which then causes a significant reduction in cost with a sudden jump. This behavior indicates the ability of the algorithm to leave local optima and move towards general and global optima, which shows the importance of using the cuckoo search algorithm in complex optimization problems. This convergence graph generally shows the strong performance of the algorithm in finding optimal solutions during different iterations and confirms that the proposed model using the cuckoo search algorithm can achieve optimal results in combined transportation.

[Figure 9](#) is the Pareto front diagram presented in this section, which is one of the most important analysis tools in multi-objective optimization and was specifically used in this study to analyze the trade-off between cost and transportation time. This diagram

represents a set of solutions where no other solution can improve the other without increasing one of the objectives (cost or time). In other words, each point on the Pareto front represents an optimal solution that has achieved a balance between reducing cost and reducing time.

In this diagram, each point represents a specific combination of cost and time for a transportation route. The points on the lower left side of the diagram represent solutions that have lower costs and time and are therefore preferred. These points form the Pareto front and are considered optimal solutions.

One of the notable features of the Pareto front diagram is that it allows decision makers to choose the appropriate solution depending on their priorities. For example, if cost reduction is the main priority, the point that has the lowest cost can be chosen, even if the transportation time is longer. Conversely, if transportation time is more important, the point that minimizes the time may be chosen, even if it is more costly.



**Figure 9.** Pareto front diagram

#### 4. CONCLUSION

In general, the research method and algorithm used in this study were able to achieve significant results. The proposed model is not only theoretically strong and reliable, but also in practice it has been able to show better performance than other similar models. In general, the use of the cuckoo search algorithm has played a key role in this research due to its unique capabilities in searching for global optima and interacting with complex data. The results obtained from the case study showed that the proposed model

can be effectively used in optimizing supply chains and combined transportation in transit corridors such as the North-South Corridor.

The proposed model, using the cuckoo search algorithm, was able to achieve significant results in reducing transportation costs and times. These results indicate the efficiency of the model in optimizing routes and selecting the best transportation methods according to existing conditions and constraints.

First, the total transportation costs for each of the proposed routes and different transportation methods were calculated and presented. These results showed that the model was able to significantly reduce transportation-related costs. For example, the best selected route for combined transportation in this study was the one that included rail and road sections from Astara to Bandar Abbas. The route from Astara to Rasht was calculated by rail, from Rasht to Qazvin and then Saveh and Qom by road, and from Qom to Isfahan, Yazd and Bandar Abbas again by rail, and this route was selected as the optimal route with a total cost of \$723.7. The cost per kilometer on this route was calculated to be about 38 cents, indicating the high efficiency of the model in reducing costs. In addition to reducing costs, the model was also able to optimize transportation times. The total transportation time on the optimal route was 57 hours, which is considered a suitable time for combined transportation on this route, given the existing conditions and constraints. The average speed of rail and road transportation was considered to be 35 and 70 km/h, respectively. Using these speeds, the calculated times achieved high accuracy. One of the important points in this study was the effect of changing the transportation method from rail to road and vice versa on costs and times. The

model showed that changing the transportation method from rail to road has a greater impact on increasing costs than changing the method from road to rail. This result could be due to the higher costs and more time associated with changing the method from rail to road. The cost of changing the transportation method from rail to road was considered to be \$60 and from road to rail was \$30, which played an important role in the final calculations.

The sensitivity analysis of the model to changes in some key parameters such as transportation speed and switching costs showed that the proposed model has high stability. For example, by increasing the speed of trains, the model was able to achieve a reduction in costs and times, and the percentage of rail transportation usage also increased. This indicates the positive impact of increasing the speed of rail transportation on the overall efficiency of the system. Overall, the results obtained from the case study show that the proposed model was able to successfully determine the most optimal routes and transportation methods in the North-South Corridor. These results can be used as a practical guide for future decisions in the field of optimizing combined transportation in supply chains and similar transit routes.

|                                               |                                                                                                                              |
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